Number 152 August 12, 1924

OCCASIONAL PAPERS OF THE MUSEUM OF ZOOLOGY

UNIVERSITY OF MICHIGAN

Ann Arbor, Michigan Published by the University

LAND AND FRESHWATER MOLLUSCS OF THE DUTCH LEEWARD ISLANDS

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Introduction

In 1920, while on the University of Michigan-Williamson Expedition to Venezuela, a small collection of land shells was obtained from the Schaarlo, back of Willemstad, Curaçao.[1] In 1922, the University of Michigan Museum of Zoölogy sent me back to the Dutch Leeward Islands to collect molluscs, reptiles, amphibians and ants. With the assistance of an additional grant from the Zoölogical Laboratory of the University of Pennsylvania, for the collection of grasshopper testes as cytological material, I was able to spend the summer, from June 11th to September 17th, 1922, in a study of all five of the islands of the group. The reptiles collected have been listed already, in a paper by Dr. A. G. Ruthven.[2]

From June 11th to 28th, Overzijde (Otrabanda), Curaçao, was the base for collecting trips. From June 29th to July

[1] 1923; *Occ. Papers, Mus. Zool. Univ. Mich.*, no. 137; pp. 1–7, pl. I.

[2] 1923; *Occ. Papers, Mus. Zool. Univ. Mich.*, no. 143.

12th, I was guest of Mr. Richard Muskus at his Landhuis Knip, near the northern end of the same island. On July 19th, the schooner "Albertina" took me to Oranjestad (Plaja Aruba), from which town a study was made of the island of Aruba, until August 10th, when I sailed, on the packet schooner "Ligia," back to Willemstad (Punta), Curaçao, and then to Kralendijk (Plaja Bonaire), Bonaire. From August 13th to September 1st, collections were made on this island, with a visit to Klein-Bonaire (Bonaire Chikitoe) on August 24th. By arrangement, the sloop "America" put me ashore for two hours, on September 1st, at the island of Klein-Curaçao (Curaçao Chikitoe). September 2nd to 17th were spent at Overzijde, Curaçao, from where trips were made to Sint Willebrordus and New Port, on the same island.

A note in regard to the locality names may not be out of place. The language of the Dutch Leeward Islands is Papiamento, which seems to have started as a dialect of Portuguese, but which has acquired words from all of the languages spoken in the West Indies. Written Papiamento was invented by Dutch orthographers, with the result that the combinations of letters, used to express certain sounds, are very different from those in the Romance languages. The larger towns and the more conspicuous topographic features have Dutch names, but the official language is infrequently heard in the islands, and the Papiamento synonyms are much more commonly used. The former are preferred throughout this paper, but the latter are occasionally added in parentheses. The spellings used here are taken from the Dutch Government 1/20000 topographic maps, but, even in these, variations occur.

My thanks are due the Government officials of the islands, especially the Procureur-General and the Government secretaries of Curaçao and the Subgovernors of Aruba and Bonaire, and also to the United States Consul, Mr. B. S. Rairden, for assistance in many ways. In addition, I found all of the people of the islands extremely hospitable and always willing to direct me to favorable localities for study. In particular,

I wish to express my indebtedness to Mr. Richard Muskus, of Campo Knip, Curaçao, whose hospitality I enjoyed for two weeks, to Mr. Gravenhorst, of Kralendijk, Bonaire, who helped me to find quarters on that island, and to Mr. and Mrs. de Veer, of Oranjestad, Aruba. I also wish to thank the firm of S. E. L. Maduro and Sons for their many courtesies, and that of John Godden and Co., for permission to visit the Tafelberg of Santa Barbara.

I am deeply indebted to Ir. G. J. H. Molengraaff, M.I., for the meteorological data which are collated in Tables I, II and III, and to Dr. N. L. Britton, who, through the kind mediation of Mr. J. M. Fogg, identified some specimens of characteristic plants. The identification and comparison of the molluscs collected were made possible by the library and collections of the Academy of Natural Sciences of Philadelphia, where Dr. H. A. Pilsbry and Mr. E. G. Vanatta were, as always, very helpful. Drawings, photographs, and preparations of radulae, etc., were made at the Zoölogical Laboratory of the University of Pennsylvania.

Environment

The Dutch West Indies, or the Netherlands Colony of Curaçao, consist of islands in the northern Lesser Antilles, and the ones studied in the Leeward Group. The island of Curaçao, from which the entire colony takes its name, is the largest of the latter, and lies in the Caribbean Sea, 47 miles north on the 69th west meridian from the coast of Venezuela, and just north of 12° north latitude. The island of Aruba is about 60 miles to the northwest; it lies on the 70th west meridian, approximately 20 miles north of the Paraguana Peninsula, and around 12° 30′ north latitude. Bonaire and the closely associated island of Klein-Bonaire are about 30 miles east of Curaçao, just northwest of 12° north latitude and 68° west longitude. Klein-Curaçao is a small coral island about 8 miles southeast of the southeastern end of Curaçao, at 12° north latitude and 68° 39.5′ west longitude.

The ocean bottom has not been mapped thoroughly in all parts adjacent to the islands, but it seems quite certain that

738 fathoms of water lie between Curaçao and the mainland. Such a depth of water would mean that a constant negative movement of the strand line would connect the Lesser Antilles, and even the Greater Antilles, to the South American mainland, before the 40 mile strait between Curaçao and Venezuela would be drained. On the other hand, the passage between Aruba and the Paraguana Peninsula is less than 40 fathoms deep in the shallowest place. The United States Hydrographic Office chart, number 964, shows one sounding of 830 fathoms between Curaçao and Aruba, but the depths between Curaçao and Bonaire, and between the last island and the groups to the east, are not mapped. Nevertheless, it seems probable that the isolation of Curaçao, Klein-Curaçao, Bonaire and Klein-Bonaire is at least directly comparable to that of the northern Lesser Antilles. As will be discussed later, this geographic separation is intensified by the ecological differences between all of the Dutch Leeward Islands and most parts of the South American mainland.

Ir. G. J. H. Molengraaff, M.I., Chief of the Weather Bureau of Curaçao, very generously sent me the meteorological data which are compiled into the following tables. As will be seen from the first of these, the climate of the Dutch Leeward Islands is influenced by an almost constant, east trade wind of considerable strength. As will be discussed later, this produces a marked difference between the eastern and western slopes on the islands. All of the records given are from points on the western side of the islands, with the exception of those from Rincon, Bonaire, which is also partially protected from the east winds.

The usual ocean currents follow quite closely the direction of the trade winds, but are deflected somewhat to the northward by the South American coast line and those of the islands. For instance, the trip from Willemstad to Oranjestad was accomplished in about 12 hours, although the schooner's sails were flapping most of the time. On the other hand, the return trip, which was said to be a fast one, required 34 hours. However, this general trend is occasionally reversed. "South

Table I. Winds at Fort Amsterdam, Willemstad, Curaçao from August, 1910, to December, 1921, inclusive[3]

	Wind Direction in Percentages								Wind Velocity Beaufort Scale (0–12)		
									8:00	2:00	6:00
	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	A.M.	P.M.	P.M.
January	0.2	14.8	84.0	0.7	0.0	0.1	0.2	0.0	2	2	2
February	0.6	13.0	84.2	1.9	0.0	0.0	0.0	0.1	2	3	3
March	0.0	13.9	84.2	1.9	0.0	0.0	0.0	0.0	3	3	3
April	0.7	9.8	86.9	1.3	0.2	1.2	0.0	0.0	3	3	3
May	0.0	8.8	88.0	3.2	0.0	0.0	0.0	0.0	3	3	3
June	0.0	6.7	92.6	0.7	0.0	0.0	0.0	0.0	3	4	3
July	0.0	7.7	91.2	1.0	0.1	0.1	0.0	0.0	3	3	3
August	0.2	7.4	88.2	3.4	0.1	0.5	0.1	0.0	3	3	3
September	0.1	6.2	87.8	5.0	0.4	0.2	0.2	0.0	3	3	3
October	0.1	8.5	79.3	7.5	2.6	1.1	0.8	0.1	2	2	2
November	0.3	13.4	78.0	6.0	1.0	1.2	0.2	0.0	2	2	2
December	0.0	13.3	83.7	2.6	0.2	0.0	0.1	0.0	3	3	3
Mean Annual	0.2	10.3	85.7	2.9	0.4	0.4	0.1	0.0	3	3	3

of Curaçao the surface current is generally to the westward, but an easterly sub-current exists and this is of such volume that it is liable entirely to overcome the surface set.''[4]

The temperatures (Table II) are remarkably uniform, with a total extreme fluctuation of 23 degrees Fahrenheit, during the period measured. The mean annual temperature (81° F.) places the islands in Calvert's zone II.[5] It is also noteworthy that the mean daily variation (8° F.), although small, is twice as great as the fluctuation in the mean monthly temperature (4° F.).

The rainfall (Table III) is as variable as the temperature is uniform. The mean annual rainfall of the four localities measured (17 to 22 inches) immediately establishes the islands as tropical semi-deserts. It will be noted that a distinct rainy season occurs in the months October to January, although the

[3] Observations missing between Nov. 2nd and 7th, 1918. The table of wind directions is reduced from one containing intermediate points; most of the N.E. and S.E. winds listed were actually observed as E.N.E. and E.S.E. winds, respectively.

[4] United States Hydrographic Office chart, number 1290.

[5] 1908; *Proc. Acad. Nat. Sci. Philadelphia;* Plate xxvi.

Table II. Temperatures at Fort Amsterdam, Willemstad, Curaçao from January, 1903, to June, 1921, inclusive[6]

	Mean Monthly		Mean Daily	Range	Extremes	
	Cent.	Fahr.	Centigrade	Fahr.	Centigrade	Fahr.
January	25.9	79	23.6–28.2	74–83	21.0–30.5	70–87
February	25.9	79	23.7–28.2	75–83	21.0–30.5	70–87
March	25.9	79	23.7–28.7	75–84	20.5–31.0	69–88
April	26.8	80	24.5–28.7	76–84	21.0–31.5	70–89
May	27.7	82	25.4–30.1	78–86	23.0–32.8	73–91
June	27.7	82	25.6–29.9	78–86	22.4–32.0	72–90
July	27.6	82	25.3–29.9	78–86	22.0–32.2	72–90
August	26.7	80	25.7–30.3	78–87	21.0–32.5	70–90
September	28.3	83	25.9–30.8	79–87	20.0–33.0	68–91
October	28.0	82	25.6–30.4	78–87	21.0–33.0	70–91
November	27.5	81	25.1–29.8	77–86	21.0–32.0	70–90
December	26.5	80	24.2–28.8	76–84	21.5–32.3	71–90
Annual	27.0	81	24.9–29.5	77–85	20.0–33.0	68–91

usual rainy period of the higher West Indian islands and the Venezuelan mainland comes between June and November. But extreme variation is the most conspicuous feature; less rain may fall in one of the wet months than the mean precipitation of the driest month. The rainfall of a single month may be much greater than that of an extremely dry year; in fact, it may be practically as great as the mean annual precipitation. In addition, my own experience, and conversation with the inhabitants, lead me to believe that the greater proportion of the downfall comes in a few torrential deluges. Attention also should be called to the fact that my study of the islands was made during the dry season, but that the preceding year and the one of my visit (1921 and 1922) were wet years (875 and 810 mm. rainfall, respectively, at Cas Chikitoe, near Willemstad, Curaçao).

All of the recorded data come from near the towns. From the vegetation, and the rainfall while I was on the islands, I suspect that the vicinity of the higher hills receives a considerably greater amount of precipitation, especially during the

[6] Not recorded from Feb. 11–17, 1905; Nov. 3–7, 1918; Sept. 1–23, 1904; Oct. 5–31, 1904; June and Sept., 1906; July and Sept. to Dec., 1919; Jan., 1920.

drier months. In fact, it seems probable that the differences between the stations recorded are quite largely due to such local factors as the height of the hills in their vicinity. However, none of the "seroes" is high or large enough to produce anything like a rain forest. Sint Christoffelberg (1,229 feet), on its western side near the summit, is the only place where bromeliads and other epiphytes are at all conspicuous.

Table III. Rainfall in Millimeters[7]

	Fort Amsterdam, Curaçao		Oranjestad, Aruba		Kralendijk, Bonaire		Rincon, Bonaire	
	Mean	Extremes	Mean	Extremes	Mean	Extremes	Mean	Extremes
January	54	9–115	50	0–151	50	3–111	63	0–167
February	30	1–102	14	0–64	32	0–95	32	1–79
March	25	1–81	15	0–56	24	0–74	18	Tr.–50
April	24	0–173	23	0–168	24	0–104	28	Tr.–185
May	11	0–54	8	0–51	13	0–48	21	Tr.–136
June	19	1–72	13	0–54	10	0–30	14	Tr.–53
July	30	2–89	21	2–45	27	4–62	27	Tr.–60
August	38	3–142	33	1–139	28	3–88	29	Tr.–98
September	27	4–89	24	2–59	15	1–38	23	0–70
October	99	1–472	74	6–252	100	Tr.–494	88	8–342
November	118	12–325	96	4–358	114	31–241	123	35–214
December	83	10–262	65	11–228	80	21–265	79	25–269
Annual	561		435	86–941	516	164–982	545	133–883

The data sent me by Ir. Molengraaff show a rather high and constant humidity, during the daytime, at Fort Amsterdam, Willemstad, Curaçao. The mean annual (August, 1910, to December, 1920) and the variations in the mean monthly relative humidity are: at 8 A. M., 74 and 73–75, respectively; at 2 P. M., 71 and 68–72; at 6 P. M., 73 and 71–74 per cent. Although I have no data to present, I believe that dew is a comparatively rare and inconspicuous phenomenon on the

[7] The records from Fort Amsterdam, Willemstad, Curaçao, cover a period of from 28 to 29 years, dependent on the month (Jan. and Feb., 1895–1923; Mar. to May, 1895–1922; June to Sept., 1894–1922; Oct. to Dec., 1894–1921). From Oranjestad, Aruba, they cover a period of 16 years (1901–1916). From the two localities on Bonaire, they cover a period of 12 years (1905–1916).

highlands and along the western sides of the islands, at least during the dry months. On the other hand, along the excessively arid eastern shores and northern and southern tips of the islands, a rather heavy dew formation seems to be the usual thing.

Land Habitats

Sometime after the Miocene,[8] the Dutch Leeward Islands must have been almost entirely submerged; so that they were largely covered with a thick coral formation. Three or four prominent beach-lines, around the hills (fig. iii–5), were formed at different stages of the emergence, and the limestone was eroded away from the central portions, so that the older rocks were extensively exposed. Recently, another period of partial submergence must have taken place, as the peculiar shape of such bays as the Schottegat (Plate I, 5–R) and Spaansch Water (2–E) on Curaçao, certainly indicate that these are sunken valleys. As the central dome was eroded away, the stream channels formed narrow outlets through the tilted limestone at the edges, and most of the present valleys have a similar shape to these submerged ones.

Fundamentally, on the basis of their igneous intrusions, the Dutch Leeward Islands have been considered a portion of a complex which includes the Goajira Peninsula and the Sierra Nevada de Santa Marta (perhaps also the Paraguana Peninsula) of the South American mainland.[9] Superficially, each island is a canoe-anticline, the long axis of which extends approximately northwest southeast. The central portion of each island is composed largely of highly metamorphosed and crumpled, Cretaceous conglomerate-schists, and of igneous

[8] Compare J. Lorié; 1887–9; *Samml. Geol. Reichsmus. Leiden,* 2 ser., Bd. I, pp. 111–149; and K. Martin; 1887, 1888; *Bericht über eine Reise nach Niederländisch West-Indien,* I and II. The latter contains a detailed discussion of the geology of the three main islands, with rather inelaborate maps of the formations.

[9] W. Sievers; 1896; *Petermanns Mitteilungen,* Vol. XLII, p. 129, and pl. X.

rocks, such as diabase, quartz-diorite (northern Aruba) and mica-porphyrite (northern Bonaire). These older rocks may resist erosion so as to form the highest hills in the islands (figs. iii–6, and vi–14), or they may be peneplainized (especially the diabase) to rolling plains (fig. vii–17), inside of the limestone ramparts (fig. iii–5) along the seashore. Most of the soil of the islands is derived from these more ancient rocks, but the rapid erosion prevents the retention of much residue, except on the more nearly level portions. As a result, almost all of the agricultural development (hofjes), except the aloe plantations, is in the valleys of these central basins.

The calcareous strata are markedly unconformable on the older rocks. The earlier limestone layers are very hard and are darker in color; the more recent ones (fig. iii–7) are simply exposed coral reefs and are quite soft and chalky in texture. Where exposed, the older limestone (fig. vi–14) erodes into characteristic jagged points, separated by irregularly rounded holes, which may be several feet in depth; thin slabs of this material ring like steel when struck. The central dome has been largely removed, but in the middle of Curaçao and on the southern ends of Aruba and Bonaire, the calcareous rocks still practically bridge each island, while capped monadnocks, such as the Tafelberg of Sint Hyronimus (Pl. I, Curaçao, 20–N) and Ronde Klip (12–P) on Curaçao, show its former extent and altitude. Usually the southwestern rim is more markedly tilted than the northeastern; the latter is often eroded almost to the shore (northern Curaçao and Aruba), or may remain as flat-topped ridges and mesas of the older limestone (for example, the coast of Hato, Curaçao; fig. v–13), while the former is carved by the canyon-like valley outlets into bold, angular hills (fig. iii–5).[10] Almost invariably, the northeastern escarpments of all of the older remnants form vertical, or even overhanging cliffs, which are commonly excavated into more or less extensive caves, and decorated with

[10] K. Martin, I, Plate IX, shows the inland side of the limestone rim from Seroe Domi to Seroe Salinja Abau, with the Tafelberg of Santa Barbara in the background.

stalactites, stalagmites and other seepage deposits (figs. iv–8, v–13). In addition, less prominent cliffs may occur above the fossil beaches on the leeward side of the hills, and the more recent coral layers quite commonly form lower ridges, which are separated from the more prominent monadnocks of older limestone by valleys parallel to the shore. The true mesas, like the Ronde Klip and the Tafelberg of Santa Barbara, are almost entirely surrounded by steep cliffs.

The flora of the islands is discussed in detail by Dr. I. Boldingh.[11] "The general impression of the vegetation of the islands Curaçao, Aruba and Bonaire is that of a dry country, where thorny shrubs and cactuses predominate . . . the vegetation has everywhere a rather uniform aspect. . . . Excepting a few less exposed parts and the higher tops of Curaçao and Bonaire, the whole vegetation may be said to have a more or less xerophile character; in many places where the soil is covered by hardly any humus, as on the numerous limestone table-lands, it becomes a poor vegetable cover . . . ; nearly everywhere the soil is clearly visible and not covered by a connected vegetation. . . . The type of vegetation might be generally described as a **Croton vegetation**, . . . determined by plants like Croton, Acacia, Lantana, Melochia, Opuntia, Melocactus. . . . *Capparis Breynia* is characteristic for the vegetation outside the lime and *Rhacoma crossopetalum* and *Antirrhoea acutata* for the lime." (Excerpts from pages 149 and 150.)

Commonly the omnipresent thorn trees are dwarfed and distorted by the dry trade winds; the foliage of the divi-divi (*Caesalpinia coriaria*) usually consists of a flat, matted fan, which only spreads out to the leeward of the trunk (fig. v–12). The giant organ-pipe cacti (Cereus) are among the most conspicuous features of the landscape; planted closely in rows, they form many of the fences (fig. vi–14), although the dead branches of *Acacia tortuosa* are as commonly used on Curaçao. The flat-jointed cacti (Opuntia) are almost everywhere, and

[11] 1914; The Flora of Curaçao, Aruba and Bonaire; Leiden.